424 Rec'd PCT/PTO 21 JUL 2000

FORM PTO-1390 U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE (REV 5 93) TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371		ATTORNEY'S DOCKET NUMBER 9052-61 U.S. APPLICATION NO (If known, see 37 C.F.R. 1.5) 09/600837
INTERNATIONAL APPLICATION NO PCT/GB99/00018	INTERNATIONAL FILING DATE 5 January 1999	PRIORITY DATE CLAIMED 6 January 1998
TITLE OF INVENTION *METHOD OF FORMING INTERCONNECTIONS BETWEEN CHANNELS AND CHAMBERS*		
APPLICANT(S) FOR DO/EO/US John Edward Andrew SHAW; Chris TURNER		

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. [X] This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.

2. [ ] This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.

3. [X] This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(l).

4. [X] A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.

5. [X] A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. [X] is transmitted herewith (required only if not transmitted by the International Bureau).
   b. [ ] has been transmitted by the International Bureau.
   c. [ ] is not required, as the application was filed in the United States Receiving Office (RO/US).

6. [ ] A translation of the International Application into English (35 U.S.C. 371(c)(2)).

7. [X] Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. [X] are transmitted herewith (required only if not transmitted by the International Bureau).
   b. [ ] have been transmitted by the International Bureau.
   c. [ ] have not been made; however, the time limit for making such amendments has NOT expired.
   d. [ ] have not been made and will not be made.

8. [ ] A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).

9. [ ] An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).

10. [ ] A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern other document(s) or information included:

11. [ ] An Information Disclosure Statement under 37 C.F.R. 1.97 and 1.98.

12. [ ] An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.

13. [X] A FIRST preliminary amendment.
    [ ] A SECOND or SUBSEQUENT preliminary amendment.

14. [ ] A substitute specification.

15. [ ] A change of power of attorney and/or address letter.

16. [X] Other items or information: International Search Report; International Preliminary Examination Report; Petition for Revival of an International Application for Patent Designating the U.S. Abandoned Unintentionally

09/600837 . 000502

533 Rec'd PCT/PTO 21 JUL 2000

U.S. APPLICATION NO. (If known, see 37 C F R. 1.50)	INTERNATIONAL APPLICATION NO	ATTORNEY'S DOCKET NUMBER
09/600837	PCT/GB99/00018	9052-61

17. [X] The following fees are submitted:

Basic National Fee (37 CFR 1.492(a)(1)-(5)):

Search Report has been prepared by the EPO or JPO **$840.00**

International preliminary examination fee paid to USPTO (37 CFR 1.482). **$670.00**

No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2)) **$760.00**

Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO. **$970.00**

International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4). **$96.00**

				CALCULATIONS	PTO USE ONLY
ENTER APPROPRIATE BASIC FEE AMOUNT = $840.00				**$840.00**	
Surcharge of **$130.00** for furnishing the oath or declaration later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(e)).				$	
Claims	Number Filed	Number Extra	Rate		
Total Claims	24 - 20 =	4	**X $18.00**	**$ 72.00**	
Independent Claims	2 - 3 =	0	**X $78.00**	**$**	
Multiple dependent claim(s) (if applicable)			**+ $260.00**	**$**	
TOTAL OF ABOVE CALCULATIONS =				**$912.00**	
Reduction by 1/2 for filing by small entity, if applicable. Verified Small Entity statement must also be filed. (Note 37 CFR 1.9, 1.27, 1.28).				**$**	
SUBTOTAL =				**$912.00**	
Processing fee of **$130.00** for furnishing the English translation later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(f)).				**$**	
TOTAL NATIONAL FEE =				**$912.00**	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property +				**$**	
TOTAL FEES ENCLOSED =				**$912.00**	
				Amount to be refunded	**$**
				charged	**$**

a. [X] A check in the amount of **$2,122.00** to cover the above fees and Petition for Revival is enclosed.

b. [ ] Please charge my Deposit Account No. ______________________ in the amount of $__________ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. [X] The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 50-0220.

NOTE: **Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.**

SEND ALL CORRESPONDENCE TO:

Robert J. Smith
Myers Bigel Sibley & Sajovec
Post Office Box 37428
Raleigh, North Carolina 27627

"Express Mail" mailing label number EL481791311US
Date of Deposit: July 12, 2000

I hereby certify that this paper or fee is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1 10 on the date indicated above and is addressed to Attn: PCT Legal Staff, BOX PCT, Commissioner for Patents, Washington, DC 20231.

Marjorie J. Pfeiffer

Marjorie J. Pfeiffer
Date of Signature: July 12, 2000

SIGNATURE Robert J. Smith

40,820
REGISTRATION NUMBER

09/600837

533 Rec'd PCT/PTO 21 JUL 2000

Attorney's Docket No. 9052-61 PATENT

IN THE UNITED STATES DESIGNATED OFFICE (DO/US)

In re: Application of Shaw et al.
Serial No.: To be Assigned
Filed: Concurrently Herewith
For: *METHOD OF FORMING INTERCONNECTIONS BETWEEN CHANNELS AND CHAMBERS*

Date: July 12, 2000

Attn: PCT Legal Staff
BOX PCT
Assistant Commissioner for Patents
Washington, DC 20231

PRELIMINARY AMENDMENT

Sir:

Prior to the examination of the above application, please amend the above-identified application as follows:

In the Claims:

4. (Amended) Method according to claim 1 **[any preceding claim]** wherein the at least one cut formed in the first substrate and the at least one cut formed in the second substrate are off-set.

5. (Amended) Method according to claim 1 **[any preceding claim]** wherein the at least one cut formed substantially perpendicular to the plane of the substrate.

6. (Amended) Method according to claim 1 **[any preceding claim]** wherein the cuts are formed by sawing.

7.(Amended) Method according to claim 1 **[any preceding claim]** wherein the cuts are formed by mechanical milling.

8. (Amended) Method according to claim 1 **[any preceding claim]** wherein the cuts are formed by laser ablation.

9. (Amended) Method according to claim 1 **[any preceding claim]** wherein the cuts are formed by photolithography.

10. (Amended) Method according to claim 1 **[any preceding claim]** wherein the cuts are formed by chemical etching.

11. (Amended) Apparatus for transporting at least one fluid, the apparatus including at least a first substrate and a second substrate which have portions removed therefrom, so as to define at least one channel, the at least one channel being interconnected according to the method of claim 1 **[claims 1 to 10]**.

19. (Amended) Apparatus according to claim 11 **[any of claims 11 to 18]** wherein the substrate is a square approximately 5×10^{-2}m x 5×10^{-2}m.

24. (Amended) A micro-fluidic device incorporating the apparatus as claimed in claim 11 **[claims 11 to 22]**.

REMARKS

Claims 1-24 are presented for examination. The above claims have been amended to better conform to U.S. practice. Applicants respectfully request substantive examination on the merits.

Respectfully submitted,

Robert J. Smith

Robert J. Smith
Registration No. 40,820

Correspondence Address:
USPTO Customer No.: **20792**
Myers Bigel Sibley & Sajovec
Post Office Box 37428
Raleigh, NC 27627
Telephone (919) 854-1400
Facsimile (919) 854-1401

"Express Mail" mailing label number EL481791311US
Date of Deposit: July 12, 2000

I hereby certify that this paper or fee is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to Attn: PCT Legal Staff, BOX PCT, Commissioner for Patents, Washington, DC 20231.

Marjorie J. Pfeiffer

Marjorie J. Pfeiffer
Date of Signature: July 12, 2000

533 Rec'd PCT/PTO 21 JUL 2000

Method of Forming Interconnections between Channels and Chambers

This invention relates to a method of forming interconnections between channels and chambers, and more particularly to such a method for use in micro-engineered fluidic devices.

Micro-engineered devices may be used to transport and control fluid flow. Such devices may be used in a variety of applications including chemical and physical analysis, chemical processing, and heat transfer. Micro-engineered fluidic devices for use in the transport of immiscible fluids are described in International Patent Applications WO 96/12540 and WO 96/12541.

The advantages of using micro-fluidic devices containing channels and chambers are:

1. Only small sample sizes are needed for analysis; and
2. Transport distances for chemical processing of fluids are usually small; and
3. Heat transfer is improved.

Channels and chambers are usually formed on planar substrates, and are hereinafter referred to as "channels". There is a need for the linking of individual channels for applications which require a high fluid throughput, as fluid flow in conventional micro-engineered devices may be very low. Channels may be produced by forming grooves or depressions on one or more faces of a substrate. Such substrates may then be bonded together. Vias may also be formed in the substrate, and may connect to channels formed therein.

A number of known methods are used to form channels on the faces of planar substrates. These include:-

1. Etching using mask patterns defined by a lithographic process such as photolithography, screen printing, or direct writing; or
2. Cutting, milling, or drilling substrates by spark erosion, or laser ablation; or
3. Deposition or building up of layers on substrates according to patterns defined by lithographic processes; or
4. Electroplating through printing or photo-defined mask layers, including the use of X-ray lithography, as in LIGA (Lithographic Galvanoformung Abformung); or
5. The build up of substrates by bonding lamina, some of which may be cut to define a pattern of grooves or depressions; or
6. Mould replication or stamping of substrates defined by any of the above processes.

A common process is to form a fluid-handling micro-engineered device by anodic bonding of glass and silicon substrates having channels formed on one or both of the substrates.

Arrangements are known in the prior art for forming external connections and interconnections in substrates. External connections to channels are achieved by vias passing through to external faces of substrates, or by having channels extend to the edge of one or more of the substrates. Vias may be formed through one or more of the substrates to form interconnections between the channels. For simple devices with few external connections it is adequate to employ these methods. Methods for connecting capillaries to channels extending to the edge of a device composed of one or more substrates are described in UK Patent Application No. 9625491.7.

It is well established for electronic devices, that minimisation of the number of external input/output connections to arrays of charge pathways on a single substrate requires the routing of connections perpendicular to the substrate plane. This is achieved through the use of vias. The same topological requirements apply to fluidic devices where various feed and exit pathways connecting to channels should not intersect with each other, other than at the channel itself. For complex devices, a large number of external connections may be required.

Devices with vias and connections in multiple planar substrates correspond to the topological forms used to provide the dense connectivity required for integrated electronic devices. Within such electronic devices, charge pathways are defined in solid, self-supporting materials. The layers of material are usually thin enough to enable sufficient planarity to be maintained, allowing deposition, photolithography and etching to be carried out with good results.

In micro-fluidic devices, channels and vias are generally of larger dimensions than corresponding pathways and vias in integrated electronic devices. Channels are not self-supporting, as are the pathways in integrated electronic devices, because the formation of a channel, or a via, involves removing a volume of the substrate. Manufacture of channels and vias therefore contributes to fragility of the device, lowering yield during fabrication. This is especially true for vias, as they are formed perpendicular to the substrate plane. In addition, the difficulty of etching high aspect ratio vias (that is, a via whose length through the substrate is greater than its width) requires that the lateral dimensions of vias in the substrate plane are similar to (or often greater than) the

thickness of the substrate in which they are formed. This last constraint may be overcome by use of techniques such as laser ablation or trench etching, but such techniques are expensive and not widely available.

It is particularly difficult to photo-define and etch mask layers within the area of a narrow channel formed by a previous fabrication sequence in a micro-fluidic device. This constraint dictates that channels for micro-fluidic devices fabricated by conventional procedures are produced with a relatively low density. This is especially true for vias. Consequently, the cost per device is increased.

Typically, the density of channels formed on a substrate cannot be greater than that indicated in Figure 1, where a is of the order of the thickness of the substrate. This applies to micro-contactor arrays with channels connecting to vias produced by anisotropic or isotropic etching of a substrate. It is therefore desirable that a way of allowing interconnection and manifolding of channels is found, without the problems of low density of channels, fragility of the device, or poor manufacturing yield.

An aim of the invention is to overcome the aforementioned problems by providing a method of constructing interconnections and/or manifolds in substrates, particularly, but not exclusively, for use in micro-fluidic devices.

According to a first aspect of the invention there is provided a method of connecting channels formed in at least one substrate by making at least one cut in at least one external face of said substrate, the cut being of sufficient depth to intersect one or more of said channels such that only the required interconnections are made by each cut.

According to a second aspect of the invention there is provided a method of connecting channels including a) forming at least one flow path in a first substrate; b) forming at least one flow path in a second substrate; c) contacting the first and second substrates to form at least one channel; and d) forming at least one cut in an external face of the first substrate, the cut being of sufficient depth to intersect one or more of the channels such that, in use, a fluid passing along a fluid pathway defined by the cut may pass into the or each channel.

Preferably the substrates are bonded before the cuts are formed therein, in order to maintain the physical integrity of a device incorporating the invention. The substrates

may be bonded via anodic or thermal bonding, or by gluing using suitable adhesives such as epoxy, acrylic, or UV curing adhesives.

The method may also include the step of making at least one cut in an external face of the second substrate, the cut being of sufficient depth to intersect one or more of said channels such that only the required interconnections are made by the at least one cut.

The method preferably includes the steps of a) forming at least one flow path in a third substrate and b) joining the third substrate to the first and second substrates.

Advantageously the at least one cut formed in the first substrate and the at least one cut formed in the second substrate are off-set in order to maintain the physical integrity of a device incorporating the invention.

The at least one cut is preferably formed substantially perpendicular to the plane of the substrate.

Cuts may be produced by micro-engineering sawing methods, which can be controlled to within $10\mu m$. Alternatively, it is possible to use mechanical milling, as long as the equipment used is of relatively high precision. Laser ablation, or photolithography and chemical etching may also be applied to produce the manifolding channels. Although, in general, mechanical cutting or milling systems are preferred.

According to a further aspect of the invention there is provided an apparatus for transporting at least one fluid, the apparatus including at least a first substrate and a second substrate which have portions removed therefrom, so as to define at least one channel, the at least one channel being interconnected according to the aforedescribed method.

Preferably the apparatus further includes a third substrate. The third substrate may be situated between the first and second substrates, or adjacent the second substrate.

Preferably the first substrate is glass.

Preferably the second substrate is silicon.

If the third substrate is situated between the first and second substrates, the third substrate is preferably a mesh of, for example, copper or steel. Alternatively, it may include a polymer. The third substrate is preferably between 1 and 10 micrometres thick.

Where the third substrate is situated adjacent the first or the second substrates, the third substrate is preferably glass. The third substrate may have portions removed therefrom so as to define at least one channel.

Preferably the substrate is a square approximately 5×10^{-2} m by 5×10^{-2} m.

The channels may be substantially straight or curved.

Preferably the channels are between 1×10^{-2} m and 5×10^{-2} m in length.

The invention may be incorporated into a micro-fluidic (or other) device.

Fluids used within the device may either be miscible or immiscible. Aqueous and/or organic material may be used within the device.

Preferred embodiments of the invention will now be described, by way of example only, with reference to the accompanying Figures, wherein:-

Figure 1 shows a plan view of channels and chambers formed on a substrate, known in the prior art;

Figure 2 shows a cross-section of two planar substrates containing channels;

Figures 3a and 3b show a cross-section of two bonded planar substrates containing channels;

Figures 4a and 4b show a plan view of two bonded planar substrates shown in Figure 3;

Figures 5a and 5b show a cross-section along line v-v' of Figure 4a and 4b respectively, where manifold cuts have been made in the substrates, in accordance with the present invention;

Figures 6a and 6b show a plan view of two bonded planar substrates shown in Figures 3a to 5a and Figures 3b to 5b respectively, where manifold cuts have been made in the substrates;

Figure 7 shows a cross-section of two bonded planar substrates along line v-v' of Figure 6a;

Figure 8 shows a cross-section of a further embodiment of the invention showing two bonded planar substrates containing channels, where manifold cuts have been made in one substrate only;

Figure 9 shows an oblique view of the embodiment shown in Figure 8;

Figure 10 shows an oblique view of a further embodiment of the present invention;

Figure 11 shows a plan view of a device incorporating the invention;

Figure 12 shows a further embodiment of the invention showing two bonded planar substrates containing two sets of channels, where manifold cuts have been made to link one set of channels only;

Figure 13a shows a cross-section of a laminated structure;

Figure 13b shows a cross-section of a laminated structure having chambers formed therein;

Figure 14a is a plan view of the laminated structures of Figure 13 showing the positions of manifold cuts;

Figure 14b is a plan view of a laminated structure, showing the positions of manifold cuts at an angle to one another; and

Figures 15a to 15d show plan views of the laminated structures of Figure 13 having manifold cuts.

Referring to Figure 2, channels 14 are formed on a surface of planar substrate 10, which in this case is glass. Channels 15 are also formed on a surface of planar substrate 12, which is this case is silicon. Vias needed to interconnect the individual channels are not formed at this stage. Substrate layers 10 and 12 are then bonded together to form channels 14 and 15, as shown in Figures 3a and 3b. The substrates may be bonded using epoxy adhesive such as EpoTek™ 353 ND, or UV curing acrylic adhesive such as Norland Optical adhesive type 81.

From Figures 3a and 4a, it can be seen that the channels 14 in substrate 10 overlap channels 15 in substrate 12 to provide regions where fluids flowing in the respective channels 14, 15 contact at an interface 18. In an alternative embodiment, however, channels 14 and 15 do not overlap and there is no interface between the channels. This embodiment is shown in Figures 3b and 4b.

Interconnections or manifolds to groups or arrays of channels 14 or 15 are formed by cuts 19, 20 made into one or more of the external faces of the bonded substrates 10 and 12, as illustrated by Figures 5 and 6. Figures 5a and 6a show bonded substrates where channels 14 and 15 overlap to form an interface 18, whereas Figures 5b and 6b shows bonded substrates where channels 14 and 15 do not overlap. The position and depth of these cuts is such that only required connections to respective channels 14 or 15 are made by each cut. Cuts 20 made to substrate 10 should not extend deeply into substrate 12 so that the physical integrity of the assembled device is maintained. For channels which are 40

micrometres in depth, cuts made to an accuracy of approximately 10 micrometres are adequate.

Two methods for forming manifolds will now be discussed. Figure 7 shows a first embodiment, where the manifolds 19 and 20 are cut in both substrate layers 12 and 10 respectively, and are offset. Cut 19 is made through substrate 12 only, to intersect channels 15. Cut 20 is made through substrate 10 only, to intersect channels 14. Figure 8 shows a further embodiment of the invention, where manifolds 20 and 21 are cut in the same substrate 10. Cut 20 is made through substrate 10, and is deep enough so that it intersects with channels 15 in substrate 12. Cut 21 is also made through substrate 10, but its depth is less than that of cut 20, so that it only intersects with channels 14 in substrate 10.

Where both substrates contain cuts, as in Figure 7, the cuts should be offset, or positioned so as not to weaken the device. Formation of the interconnections generally involves at least some of the cuts through a substrate sufficiently to intersect the channels 14, 15 to be linked, and not continuing through to the interface 18 between bonded substrates 10, 12.

Where one of the substrates is transparent (substrate 10 in this case), it is advantageous to form all the manifold cuts through the transparent substrate, as in Figures 8 and 9. This allows more precise alignment of the cuts with the channels on further substrate layers.

The examples shown diagrammatically in Figures 2 to 9 are that of a micro-contactor. Similar steps may be taken to form other micro-fluidic devices from various planar substrates, provided that such substrates can be bonded and accurately cut. For example, in Figure 10, substrate 11 having manifold cuts 22, is bonded to substrates 10 and 12, which themselves contain manifold cuts 19 and 20. The resulting device has an increased manifold cross-section, and flow capacity is increased.

The depth of cuts 19 is not critical, as long as the cuts are deep enough to intersect with the channel which is to be connected with the cut, and does not pass far enough into a further substrate to weaken the assembly. For a micro-contactor, it is required that the manifolding connections do not cross the interface between the channels 14 and 15. If manifolding connections cross the interface, fluids tend to mix, and establishment of a stable fluid interface position is prevented. This is important for manifolding positions 21 shown in Figure 8, where pairs of contactor channels 14 and 15 intersect the plane of the manifold cut. Here it must be ensured that the depth of the cut is limited to a range

sufficient to intersect predetermined channels 14 and 15 etched into the substrate being cut, while not allowing the cut to reach the interface between the substrates.

The restriction on the depth of manifold cuts applies to structures other than micro-contactors.

The method of the invention may also be applied to any fluidic structure where it is required that channels to be interconnected may not intersect another set of channels. Here, channels 14 and 15 are formed in a layer of substrate 10. Channels 14 are deeper than channels 15, so that manifolding cuts made to connect channels 14 do not link channels 15. An example of this is shown in Figure 12. This concept may be of use in a heat exchanger, for example. In addition to channels 14, 15 carrying fluids, the channels may be an electronically conducting conduit, or a light guide or other structure situated between the channels to be connected, but which must remain isolated from the manifolding.

Figures 13a and 13b show a cross-section of a bonded, layered structure in which manifold cuts have not yet been formed. The bonded structure shown in Figure 13a includes a thin middle layer 30 of substrate, the central portions of which are bonded to an upper substrate layer 32a, and a lower substrate layer 32b. The outer regions of one side of layer 30 are bonded to a first substrate layer 10, and the outer regions of the other side of layer 30 are bonded to a second substrate layer 12. Material 32 (which is in contact with the central portions of layer 30) can be dissolved or melted out at a later stage. Layers 32a,b may, for example, contain a polymer or a polymer/wax mix, a metal such as copper, or an alloy such as steel which may be in the form of a mesh. The layers of material 32a and 32b are further bonded to respective layers of substrate 10 and 12, such that when the material 32 is removed, respective chambers 34a and 34b are formed in the substrate layers 10 and 12.

The laminated structure may, alternatively, be formed by bonding the outer regions of one side of layer 30 to a first substrate layer 10, and on the other by a second substrate layer 12, the substrate layers 10 and 12 having cut-away portions so as to form chambers 34a,b without the need for layers 32a,b. Such a laminated structure is shown in Figure 13b. This structure provides less support than that shown in Figure 13a, but the outer uncut layers 10,12 provide physical stability to the whole structure during assembly and bonding, thus reducing distortion of the layered structure.

Figure 14a shows a plan view of the laminated structures of Figures 13a and 13b, indicating the positions of the manifolding cuts 19 and 20. In this structure, the manifolding cuts 19 and 20 run parallel to each other. However, the manifolding cuts may be made so that they are at an angle to each other, as shown in Figure 14b. The angle should be high enough in order that the device is not weakened.

Figures 15a to 15d show cross-sections of the laminated structures of Figures 13a and 13b having various manifolding cuts formed therein. Figure 15a shows a laminated structure having manifolding cuts 20 and 19 formed in substrates 10 and 12 respectively. In this case, the cuts are made as far as layers 32a,b. The material 32 is then removed (as previously discussed) in order to form chambers 34a,b which are connected to channels 20 and 19. Cuts 19 and 20 are offset so as not to weaken the device. Figure 15c shows a layered structure having manifolding cuts 20 and 21 made in the external face of substrate 10. Cut 20 extends to the upper layer 32a, and cut 21 extends (via layer 30) to the lower layer 32b. When the material of layers 32a and 32b is removed, respective chambers 34a and 34b are formed. Chambers 34a and 34b are linked via manifolding cuts 20 and 21, respectively.

Figure 11 shows a schematic plan view of a device having a number of channels 14, 15 and manifold cuts 20, 21. The structure of the device is the same as that shown in Figures 8 and 9. Organic material passes through channels 15 formed in silicon substrate 12 via manifolding cuts 20. Cuts 20 pass through the glass substrate 10 and silicon substrate 12 in order to intersect channels 15 formed in the silicon substrate 12. Aqueous material flows in channels 14 formed in glass substrate 10 via manifolding cuts 21. Here the organic material used in a mixture of Xylene and TBP (tributylphosphate) containing dissolved iron ions (Fe^{3+}), and the aqueous material is hydrochloric acid. Where channels 14 and 15 meet, the aqueous and organic materials come into contact. There is a transfer of iron ions from the organic material to the aqueous material. This reaction is an example of a liquid-liquid solvent extraction process and is used, for example, in the pharmaceutical and nuclear industries. The organic and aqueous materials then exit from the device.

Devices produced using this method may have 120 micro-contactors of length 14mm, formed in an area of substrate 50 mm square. This is approximately ten times the density of channels achievable using past methods of etching through a substrate and using structures such as those shown in Figure 1 having vias 2 and channels 4. Fluid flow and transfer rates for devices produced using the present invention have improved by a factor of 120 over the methods in the prior art.

In summary, devices manufactured according to the method of forming interconnections of channels as herein described has the following advantages:

1. better utilisation of space/higher packing density of channels than other methods;
2. improved yield as the channels formed in one substrate are supported by another substrate;
3. improved yield due to the substrates being less likely to break during the bonding process than using other methods; and
4. improved strength of the assembled device.

The invention has been described by way of a number of embodiments and it will be appreciated that variation may be made to these embodiments without departing from the scope of the invention.

Claims

1. Method of connecting channels including a) forming at least one flow path in a first substrate; b) forming at least one flow path in a second substrate; c) contacting the first and second substrates to form at least one channel; and d) forming at least one cut in an external face of the first substrate, the cut being of sufficient depth to intersect one or more of the channels such that, in use, a fluid passing along a fluid pathway defined by the at least one cut may pass into the at least one channel, characterised in that the substrates are bonded before the at least one cut is formed therein.

2. Method according to claim 1 including the step of making at least one cut in an external face of the second substrate, the cut being of sufficient depth to intersect one or more of said channels such that only the required interconnections are made by the at least one cut.

3. Method according to claim 2 including the steps of a) forming at least one flow path in a third substrate and b) joining the third substrate to the first and second substrates.

4. Method according to any preceding claim wherein the at least one cut formed in the first substrate and the at least one cut formed in the second substrate are off-set.

5. Method according to any preceding claim wherein the at least one cut is formed substantially perpendicular to the plane of the substrate.

6. Method according to any preceding claim wherein the cuts are formed by sawing.

7. Method according to any preceding claim wherein the cuts are formed by mechanical milling.

8. Method according to any preceding claim wherein the cuts are formed by laser ablation.

9. Method according to any preceding claim wherein the cuts are formed by photolithography.

10. Method according to any preceding claim wherein the cuts are formed by chemical etching.

11. Apparatus for transporting at least one fluid, the apparatus including at least a first substrate and a second substrate which have portions removed therefrom, so as to define at least one channel, the at least one channel being interconnected according to the method of claims 1 to 10.

12. Apparatus according to claim 11 further including a third substrate situated between the first and second substrates.

13. Apparatus according to claim 11 further including a third substrate situated adjacent the second substrate, the third substrate having portions removed therefrom so as to define at least one channel.

14. Apparatus according to claim 11 wherein the first substrate is glass.

15. Apparatus according to claim 11 wherein the second substrate is silicon.

16. Apparatus according to claim 12 wherein the third substrate is a mesh.

17. Apparatus according to claim 12 wherein the third substrate includes a polymer.

18. Apparatus according to claim 13 wherein the third substrate is glass.

19. Apparatus according to any of claims 11 to 18 wherein the substrate is a square approximately 5×10^{-2} m x 5×10^{-2} m.

20. Apparatus according to claim 11 wherein the channels are substantially straight.

21. Apparatus according to claim 11 wherein the channels are substantially curved.

22. Apparatus according to claim 11 wherein the channels are between 1×10^{-2} m and 5×10^{-2} m in length.

23. Method of connecting channels formed in at least one substrate by making at least one cut in at least one external face of said substrate, the cut being of sufficient

depth to intersect one or more of said channels such that only the required interconnections are made by each cut.

24. A micro-fluidic device incorporating the apparatus as claimed in claims 11 to 22.

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : B01J 19/00, F28F 27/02 — A1

(11) International Publication Number: WO 99/34909

(43) International Publication Date: 15 July 1999 (15.07.99)

(21) International Application Number: PCT/GB99/00018

(22) International Filing Date: 5 January 1999 (05.01.99)

(30) Priority Data:
9800220.7 6 January 1998 (06.01.98) GB

(71) Applicant (*for all designated States except US*): CENTRAL RESEARCH LABORATORIES LIMITED [GB/GB]; Dawley Road, Hayes, Middlesex UB3 1HH (GB).

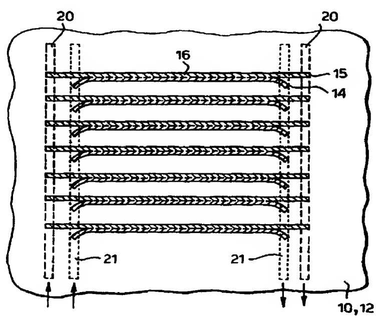
(72) Inventors; and
(75) Inventors/Applicants (*for US only*): SHAW, John, Edward, Andrew [GB/GB]; 45 Colne Avenue, West Drayton, Middlesex UB7 7AL (GB). TURNER, Chris [GB/GB]; 56 Waterside, Uxbridge, Middlesex UB8 2LQ (GB).

(74) Agent: WALKER, Neville, Daniel, Alan; QED I.P. Services Limited, Dawley Road, Hayes, Middlesex UB3 1HH (GB).

(81) Designated States: AU, BR, CA, IL, JP, RU, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: METHOD OF FORMING INTERCONNECTIONS BETWEEN CHANNELS AND CHAMBERS



(57) Abstract

A method of forming interconnections between channels and/or chambers for use in a micro–fluidic device. Two planar substrates (10, 12) (usually glass and silicon respectively) having etched channels (14, 15) are bonded together to form volmes (16) where the channels (14, 15) overlap. A manifolding cut (20) is then made through the glass to intersect channels (15) in the silicon layer. Another cut (21) is made through the glass, intersecting glass channels (14) only. An organic solution is passed into cut (20), and flows through silicon channels (15). An aqueous solution is passed into cut (21), and flows through glass channels (14). The solutions meet in the region (16), where matter is transferred from one solution to the other.

Fig.1.

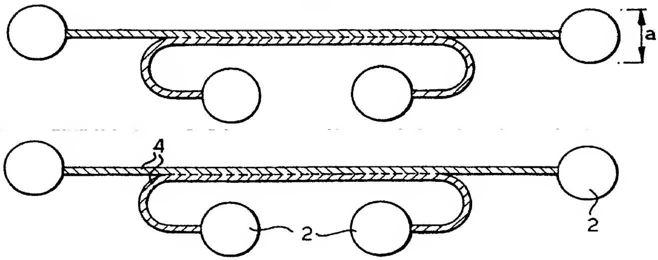


Fig.2.

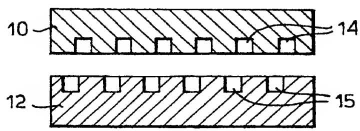


Fig.3a.

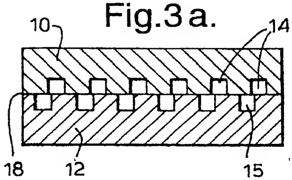


Fig.3b.

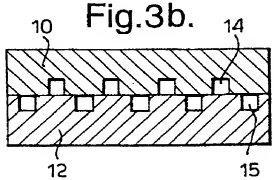


Fig.4a.

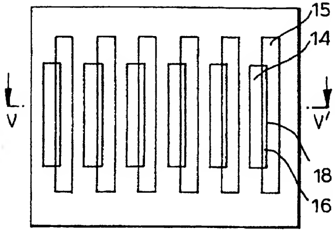


Fig.4b.

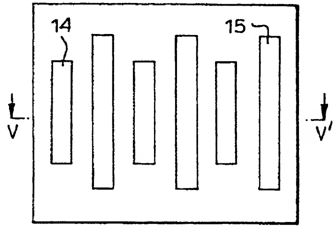


Fig.5a.

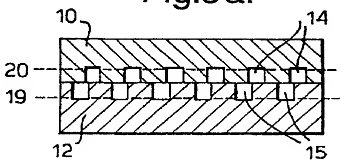


Fig.5b.

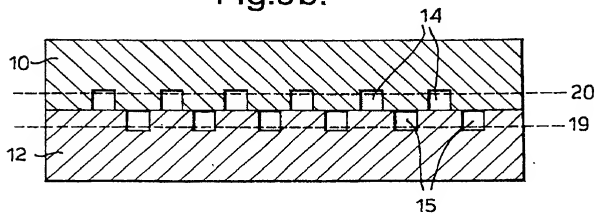


Fig.6a.

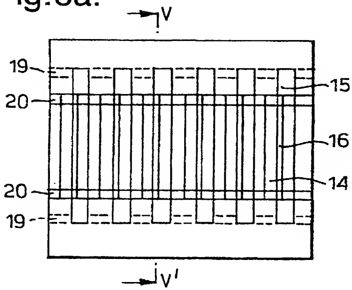


Fig.6b.

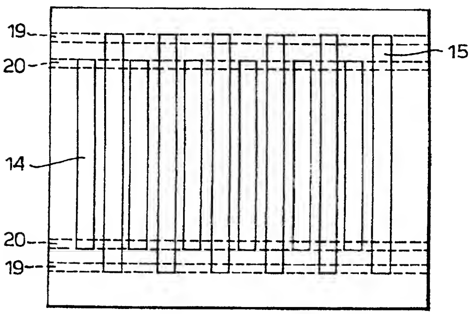


Fig.7.

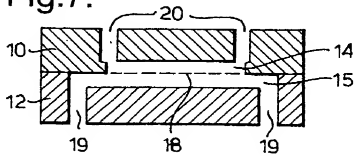


Fig.8.

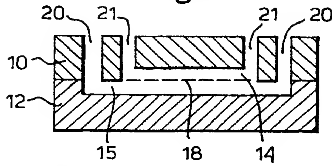


Fig.9.

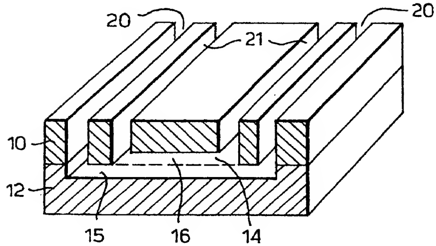


Fig.10.

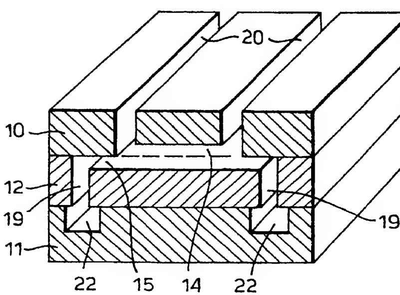


Fig.11.

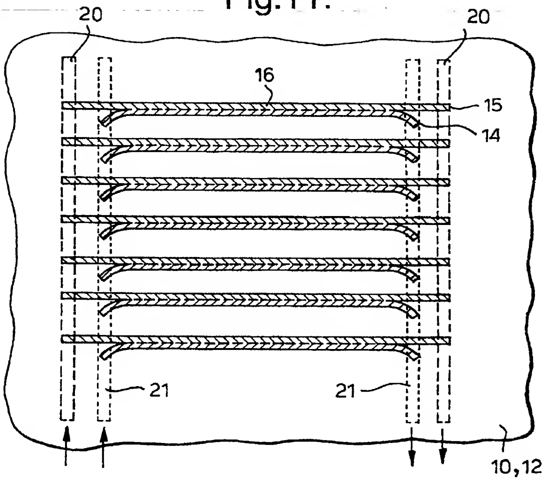


Fig.12.

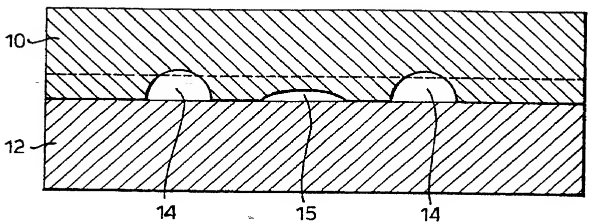


Fig.13a.

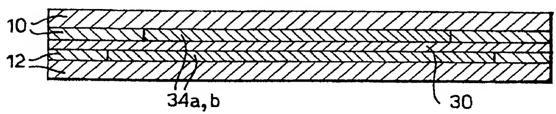


Fig.13b.

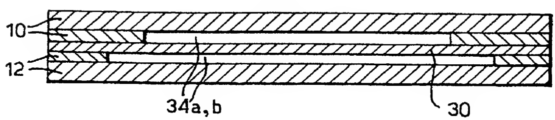


Fig.14a.

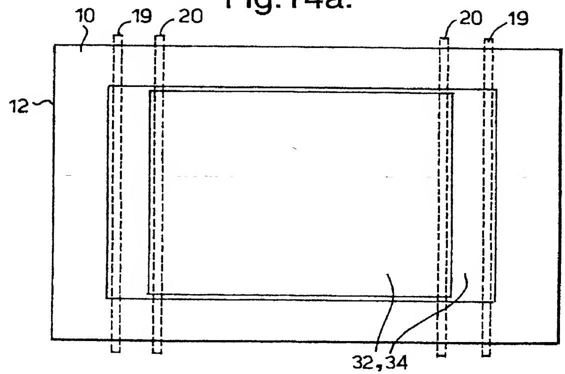


Fig.14b.

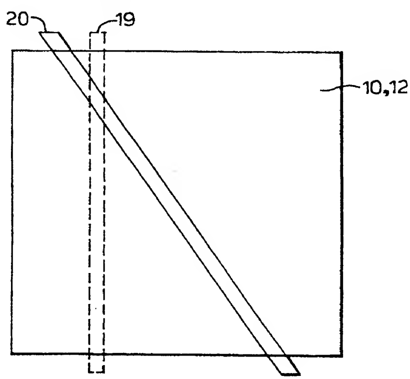


Fig. 15a.

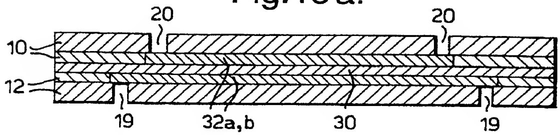


Fig. 15b.

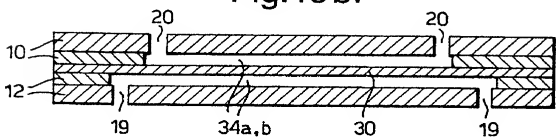


Fig. 15c.

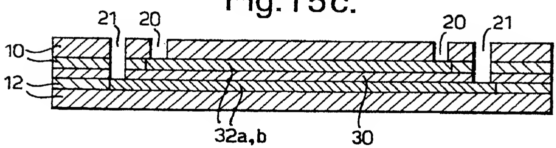
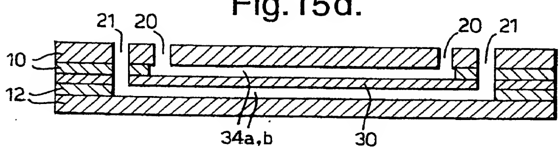


Fig. 15d.



DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION

Attorney Docket No. 9052-61

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled **METHOD OF FORMING INTERCONNECTIONS BETWEEN CHANNELS AND CHAMBERS,**

the specification of which

☐ is attached hereto

OR

☒ was filed on July 12, 2000 as United States Application No. 09/600,837.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37 Code of Federal Regulations, §1.56, including material information that became available between the filing date of the prior application and the National or PCT International filing date of the continuation-in-part application, if applicable.

I hereby claim foreign priority benefits under Title 35, United States Code, § 119(a)-(d) or § 365(b) of any foreign application(s) for patent or inventor's certificate, or § 365(a) of any PCT International application which designated at least one country other than the United States of America, listed below and have also identified below any foreign application for patent or inventor's certificate, or of any PCT International application having a filing date before that of the application on which priority is claimed.

9800220.7	Great Britain	01/06/1998	☒ Yes ☐ No
Number	Country	MM/DD/YYYY Filed	Priority Claimed
			☐ Yes ☐ No
Number	Country	MM/DD/YYYY Filed	Priority Claimed
			☐ Yes ☐ No
Number	Country	MM/DD/YYYY Filed	Priority Claimed

I hereby claim the benefit under Title 35, United States Code, § 119(e) of any United States provisional application(s) listed below.

None	
Application Number(s)	Filing Date (MM/DD/YYYY)

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s) or § 365(c) of any PCT international application designating the United States of America, listed below.

PCT/GB99/00018	01/05/1999	Published
Appln. Serial No.	Filing Date	Status Patented/Pending/Abandoned
Appln. Serial No.	Filing Date	Status Patented/Pending/Abandoned

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following registered attorney(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. I also appoint the following registered attorney(s) to represent me before all competent International Authorities in connection with any and all international applications filed by me with an appropriate receiving office claiming priority to the U.S. application. I also appoint the following registered attorney(s) to make or receive payment on my behalf in connection with the filing of such international applications.

Customer Number:

20792

PATENT TRADEMARK OFFICE

Send correspondence to: Robert J. Smith

~~Customer~~ Number:

20792

PATENT TRADEMARK OFFICE

Direct telephone calls to: Robert J. Smith
(919) 854-1400

Facsimile: (919) 854-1401

1-60

Full name of first inventor: **John Edward Andrew Shaw**

Inventor's Signature: John Shaw Date: 23rd July 2002

Residence: Middlesex, Great Britain GB3

Citizenship: Great Britain

Mailing Address: 45 Colne Avenue
West Drayton
Middlesex UB7 7AL, Great Britain

Full name of second inventor: **Chris Turner**

Inventor's
Signature: Date: 17/7/02

Residence: Middlesex, Great Britain GB3

Citizenship: Great Britain

Mailing Address: 56 Waterside
Uxbridge
Middlesex UB8 2LQ, Great Britain